# Advanced Design for Signal Integrity and Compliance
# Final Report

**Gabriele Borello** ***S252845*****,**
**Giulia Colonna** ***S253145*****,**
**Gianmarco Canzonieri** ***S244123***

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# Chapter 1

# Measuring Characteristic Impedance of a Transmission Line

## 1.1 Introduction & Setup

Considering as a reference the experiment **3.2**, provided the manual *Introduction to Signal Integrity*.
The required setup for this experiment is shown in Fig: 1.1, with particular requirements in terms of components. The table Tab: 1.1 shows the elements required by the original setup and the substitutions adopted since some of them were not available or non compliant with the specs.
Where also required to measure the value of the resistances use, in particular the value of $R_s$, shich is shown in Tab: 1.1 as well.

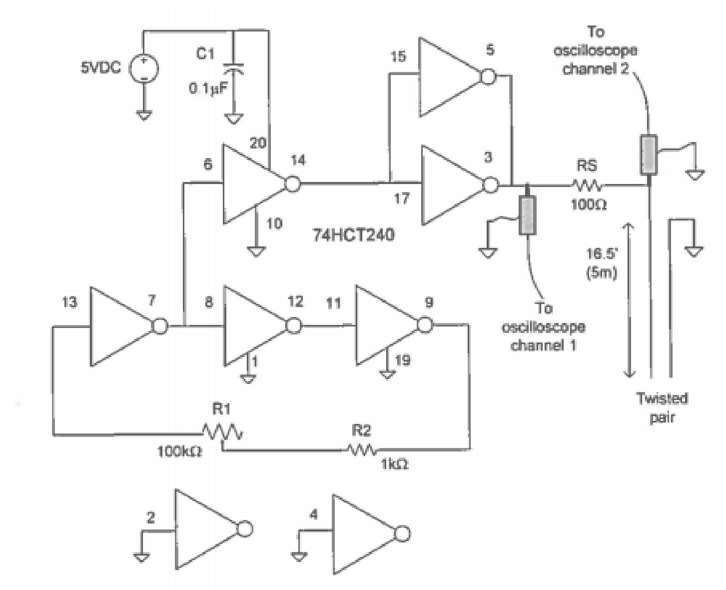


Figure 1.1: Required setup by the manual.

| | Required | Available | Measured |
|---|---|---|---|
| IC: | 74HCT420 | 7AHCT04 | |
| $R_s$: | $100\Omega$ | $100\Omega$ | $99.665\Omega$ |
| $R_2$: | $1k\Omega$ | $1k\Omega$ | $0.985k\Omega$ |
| Potentiometer: | $100k\Omega$ | $100k\Omega$ | |
| Decouplig Capacitance $C_1$: | $0.1\mu F$ | $0.1\mu F$ | |
| $V_{al}$: | $5VDC$ | $5VDC$ | $4.1VDC$ |
| cable: | CAT5e x 5m | CAT5e x 5m | |

Table 1.1

The number of required inverters required for this project is 6, with 2 grounded in the original schematic. With the available model of IC, we needed actually two of them, due to the fact that was required to have a *pulse width* on channel 1 of $200ns$, with only one IC (74HCT04) we were able to reach only a width of $10ns$. Even though the actual width was not critical, for the sake of observe correctly a plateau appearing in the pulse (required at *point 7*), we added to the ring oscillator 2 more inverters according to the pin assignment of the model to enlarge the period.
The added gates introduce some delay, but in this way we were able to reach $50ns$ with the maximum value of partition at the potentiometer, which was enough to observe the phenomenon.

## 1.2 Work progress & Results

### Observing two identical wave forms

At channel 1 and channel 2 of the oscilloscope we should observe to identical wave forms as depicted in Fig: 1.2.

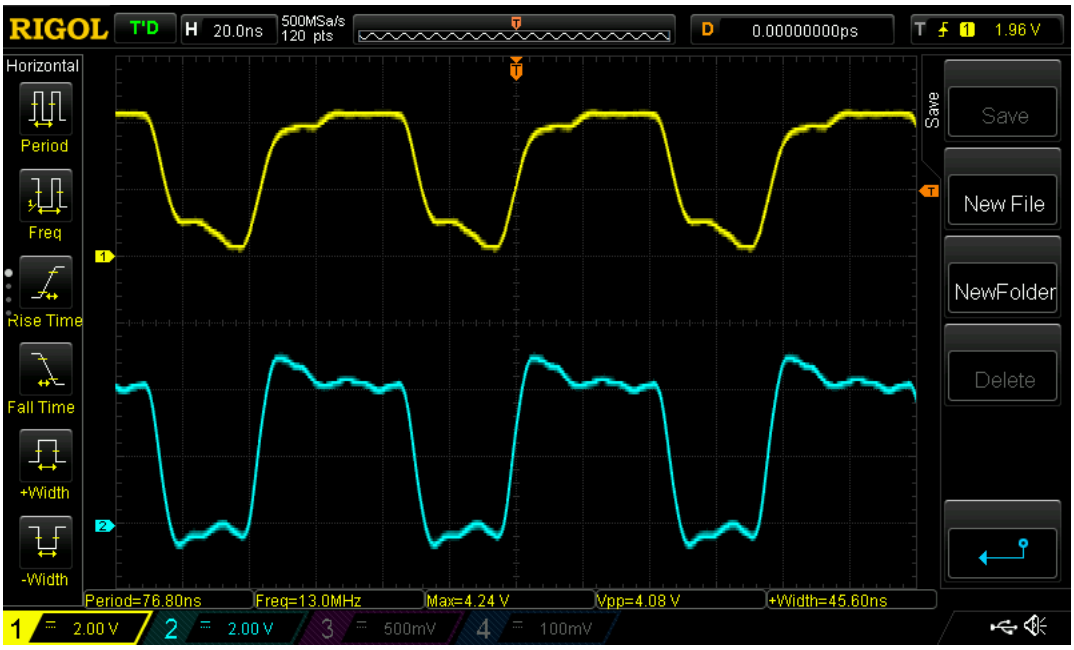


Figure 1.2: Waves without connecting yet the solid blue color of the cable to $R_s$.

**Observe changing in wave forms**

As required by *point 7* in the text, the two wave forms are changed when the solid blue is connected to resistor $R_s$,Fig: 1.3.

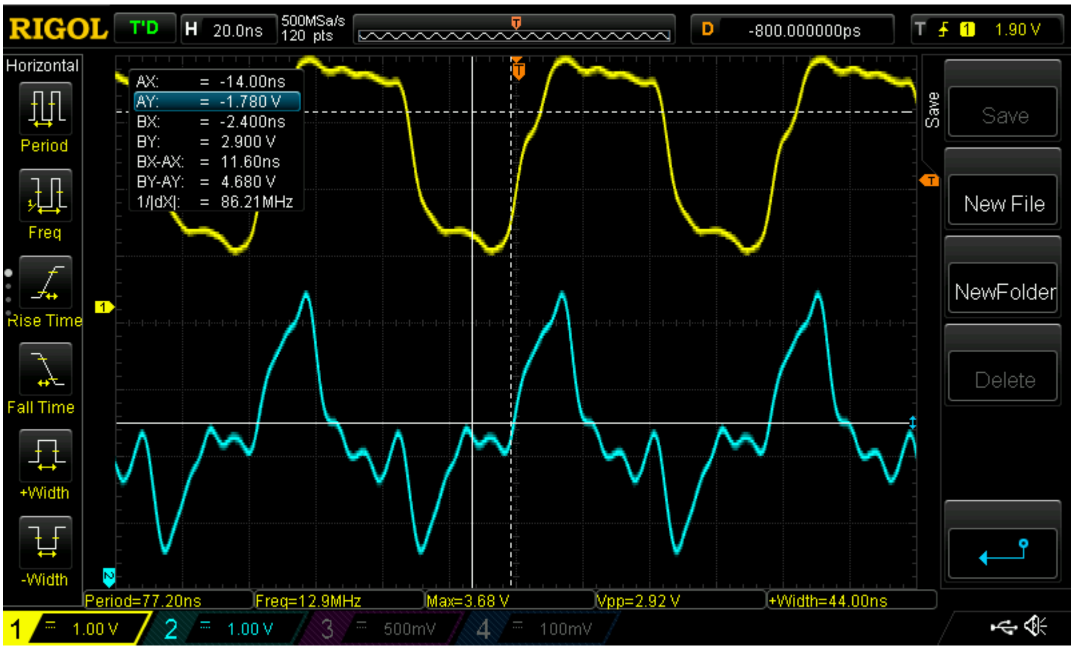


Figure 1.3: Waves connecting the solid blue color of the cable to $R_s$. The signal from channel 2 is shifted to the left due to the delay added in the system by adding two inverters in the ring oscillator, respect to the original configuration.

The actual *width of the plateau* is $12ns$ and the height is $1.4V$.
Computing the value for the input resistance of the transmission line:

$$R_L = \frac{V_{RL} R_S}{V_{out} - V_{RL}} = \frac{(1.4)(99.665)}{4.1 - 1.4} = 51.67\Omega \tag{1.1}$$

The result is coherent in terms of order of magnitude respect to the one obtained in the manual in the *calculation example*.

## 1.3 Supplemental Exercises

In *Appendix A* were suggested some values suitable for $R_s$ to repeat the experiment and the calculations. The Tab: 1.2 shows the results:

| | Resistance $R_s$ | Measured $R_s$ | Widht$[ns]$ | Height$[V]$ | $R_L$ |
|---|---|---|---|---|---|
| $Rs_1$: | $22\Omega$ | $21.83\Omega$ | $12.80$ | $2.4$ | $30.81\Omega$ |
| $Rs_2$: | $220\Omega$ | $218.00\Omega$ | $12.80$ | $1.7$ | $154.42\Omega$ |
| $Rs_3$: | $1k\Omega$ | $0.98k\Omega$ | $16$ | $850e-3$ | $256.31\Omega$ |

Table 1.2

We can notice a slightly patterned behaviour according to increasing values of $R_s$: the width of the plateau increases while the peak decreases, leading to higher values for $R_L$ .
In Fig: 1.4 there is an example of the wave obtained with $R_{s3} = 1k\Omega$.

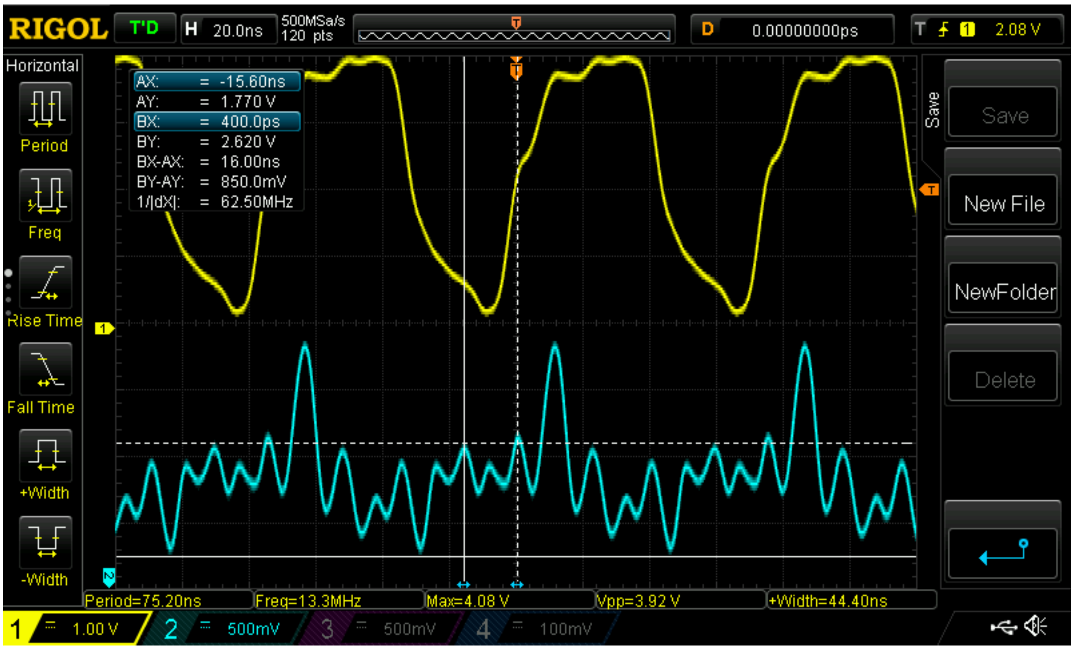


Figure 1.4: Some type of distorsion is present due to the fact that the width of the original signal is less than $200ns$.

# Chapter 2

# Termination Effect on Far End Cross talk

## 2.1 Introduction & Setup

We exploited the set up shown in Fig: 2.1 in order to observe the effects on terminating the aggressor and victim have on far end cross talk.
The ring oscillator maintains the same configuration as the one described in the first chapter. The components used are also the same.
For all the measures we set the oscilloscope trigger on the external trigger, in particular, on falling edge of the signal detected on *Channel 3*.

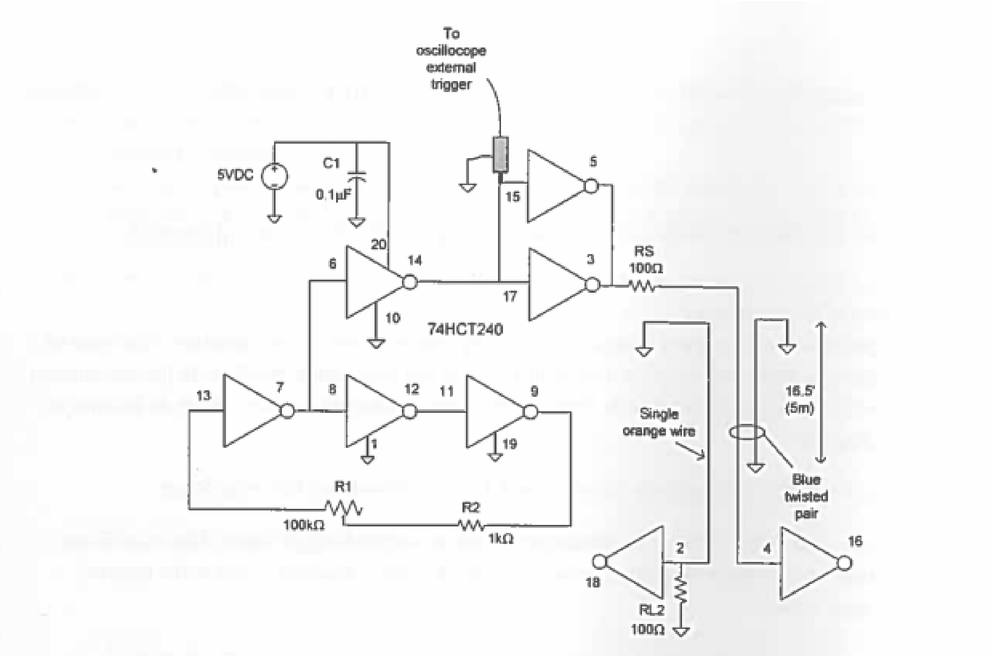


Figure 2.1

## 2.2 Work progress & Results

The pulse observed has the same width as before, $50ns$, but it was not critical.
With $R_s$ shortened and $R_{L2}$ not connected yet, we can note in Fig: 2.2 that the signal in *Channel 2* ought to be at logic high level, but the cross talk causes the pin to pulse low, it is very visible every time there is a positive peak on *Channel 1*.

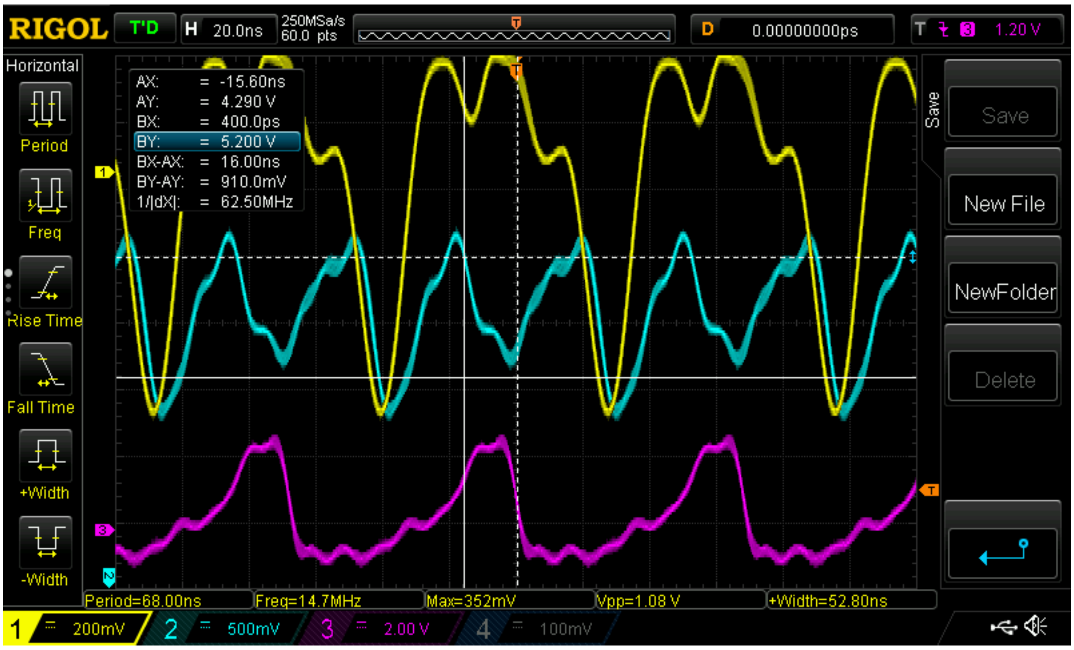


Figure 2.2

Repeating the measures in various conditions with a $R_{L2}$ value of $99.46\Omega$:

- Attach $R_{L2}$ with $R_s$ shortened :

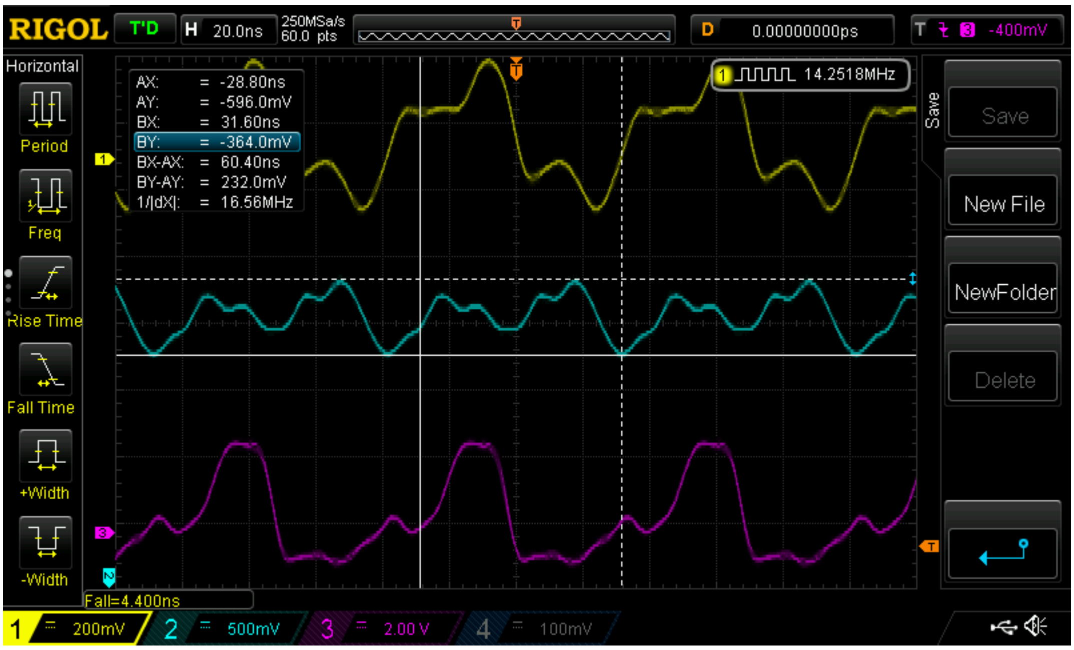


Figure 2.3

- Removing $R_{L2}$ and removing the wire that was shortening $R_s$ :


Figure 2.4

- Removing $R_{L2}$ and reattach the jumper that was shortening $R_s$ and shortening the orange wire to ground with $100\Omega$

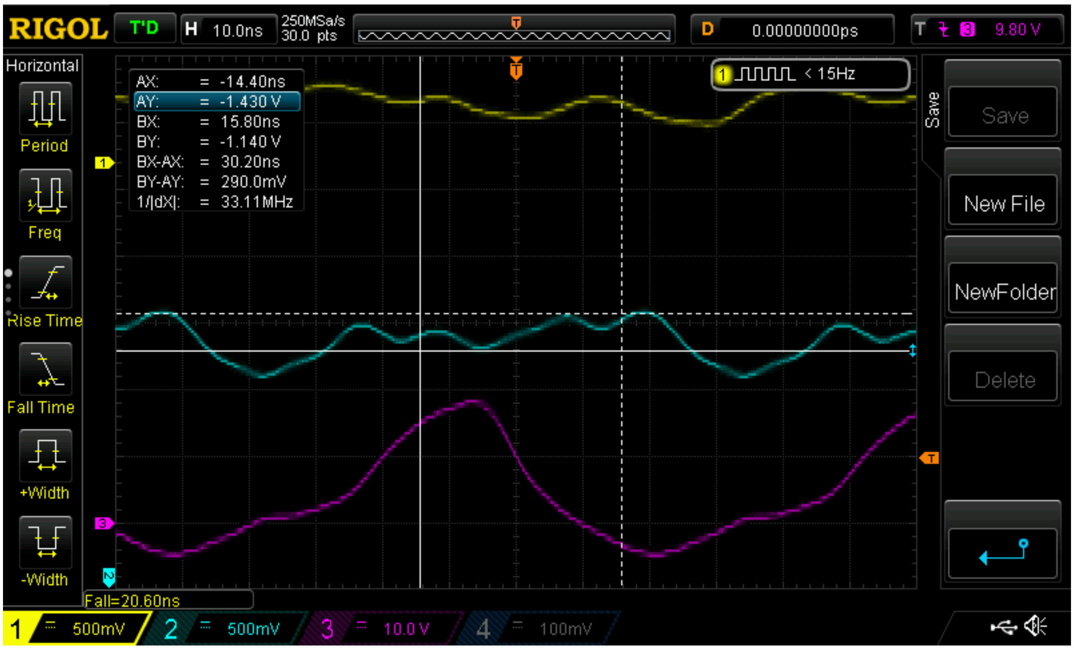


Figure 2.5

The measurements show that attaching $R_{L2}$ resistor Fig: 2.3 can improve significantly cross talk, measuring only a voltage noise ( $232mV$ ) that is no more comparable with the amplitude of the signal at logic level high, like the one observed in the worst case in Fig: 2.2 ($\approx 1V$!) .

# Chapter 3

# Wide band Guanella Balun

## 3.1 Introduction & Setup

The purpose of this experience is, considering our DUT as the Guanella Balun, to characterize the device even in operating condition and validating the specification given by the creator of this project.
In particular, Guanella Balun takes a signal from an unbalanced source, referenced to ground, to a balanced one, floating with respect to ground. It is usually found in RF circuits (push-pull amplifiers) and antennas. Moreover, they can be designed to perform an impedance transformation for matching purposes.
The requirements for the measurments with the VNA are:

- *Output Power* : $4dBm$;
- *Start frequency* : $30kHz$;
- *Stop frequency* : $100MHz$;
- *Sweep* : logarithmic;
- *Number of points* : $801$;

The equivalent of the device is reported in Fig: 3.1.
For the set up, we were not able to use $30kHz$ as a starting point, hence we used $300kHz$, due to the limitation of the VNA available in the laboratory.
One possibility was also to increase by one decade the stop frequency, but since the employed model is accurate just for low frequencies there was no point on further increasing the frequency.

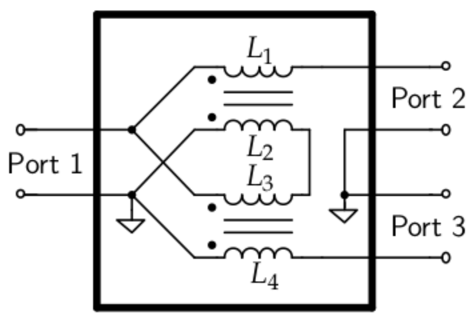


Figure 3.1

The scattering parameters measured with the VNA are normalized with respect to $50\Omega$ to all ports. Since the normalization impedance should emulate the operating load of the device for the parameters to be meaningful, a renormalization of the matrix as been adopted, as the following:

$$S' = A^{-1}\Big(S - \Gamma\Big)\Big(I - \Gamma S\Big)^{-1} A \tag{3.1}$$

Where $S^{'}$ is the transformed scattering matrix, $S$ is the original, $I$ is the identity matrix, $\Gamma$ is the reflection coefficients matrix.
The $A$ matrix is defined as:

$$A = \begin{Bmatrix} 2\frac{\sqrt{Z'_{01}Z_{01}}}{Z'_{01}+Z_{01}} & 0 & 0 \\ 0 & 2\frac{\sqrt{Z'_{02}Z_{02}}}{Z'_{02}+Z_{02}} & 0 \\ 0 & 0 & 2\frac{\sqrt{Z'_{03}Z_{03}}}{Z'_{03}+Z_{03}} \end{Bmatrix} \tag{3.2}$$

$$\Gamma = \begin{Bmatrix} \frac{Z'_{01}-Z_{01}}{Z'_{01}+Z_{01}} & 0 & 0 \\ 0 & \frac{Z'_{02}-Z_{02}}{Z'_{02}+Z_{02}} & 0 \\ 0 & 0 & \frac{Z'_{03}-Z_{03}}{Z'_{03}+Z_{03}} \end{Bmatrix} \tag{3.3}$$

In the report given to explain the experiment the equation reported for $\Gamma$ elements was wrong because a subtraction was performed at the denominator instead of an addition, we use the correct equation in the computation.
Since all measurement obtained with the VNA are inherently single-ended, a further manipulation is needed to convert the scattering parameters in a more useful form by separating the differential contribution from the common-mode one.
Thank to this transformation we switch from the configuration showed Fig: 3.2 to Fig: 3.3, obtaining the following matrix of results:

$$\begin{Bmatrix} b_{1s} \\ b_{2d} \\ b_{2c} \end{Bmatrix} = \begin{Bmatrix} S_{11ss} & S_{12sd} & S_{12sc} \\ S_{21ds} & S_{22dd} & S_{22dc} \\ S_{21cs} & S_{22cd} & S_{22cc} \end{Bmatrix} \begin{Bmatrix} a_{1s} \\ a_{2d} \\ a_{2c} \end{Bmatrix} \tag{3.4}$$

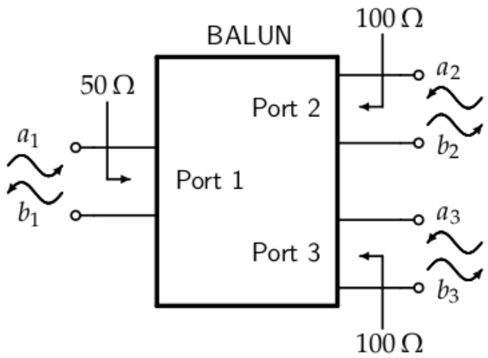


Figure 3.2

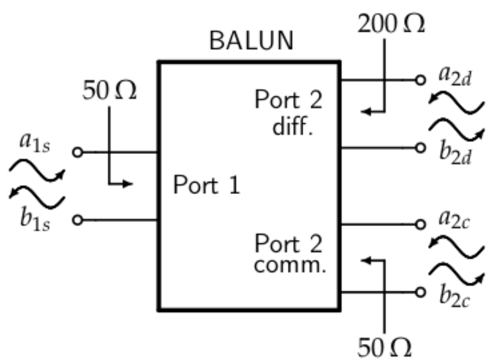


Figure 3.3

## 3.2 Work progress & Results

We evaluate the *Voltage Standing Wave Ratio*, for both the input and the output. The results shown in Fig: 3.4 are coherent with the ones obtained in the presentation, while the values reported in Fig: 3.5 exceed the specification given . This discrepancy could be linked to the fact that the terminations, the $50\Omega$ or $100\Omega$ loads presented at the output port, have a capacitive behavior, which were measured also with the VNA.
All the comparisons between the requirements and the obtained values are reported in Tab: 3.1.

$$VSWR_{in} = \frac{1+ \mid S_{11,ss} \mid}{1- \mid S_{11,ss} \mid} \tag{3.5}$$

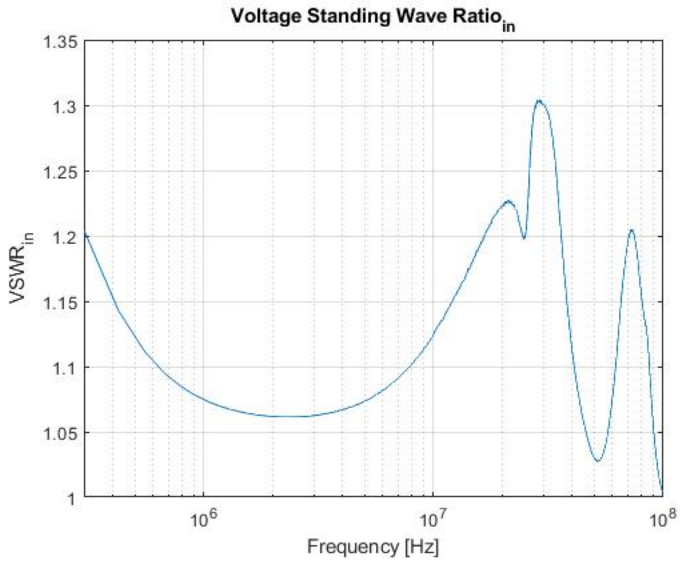


Figure 3.4

$$VSWR_{in} = \frac{1+ \mid S_{22,dd} \mid}{1- \mid S_{22,dd} \mid} \tag{3.6}$$

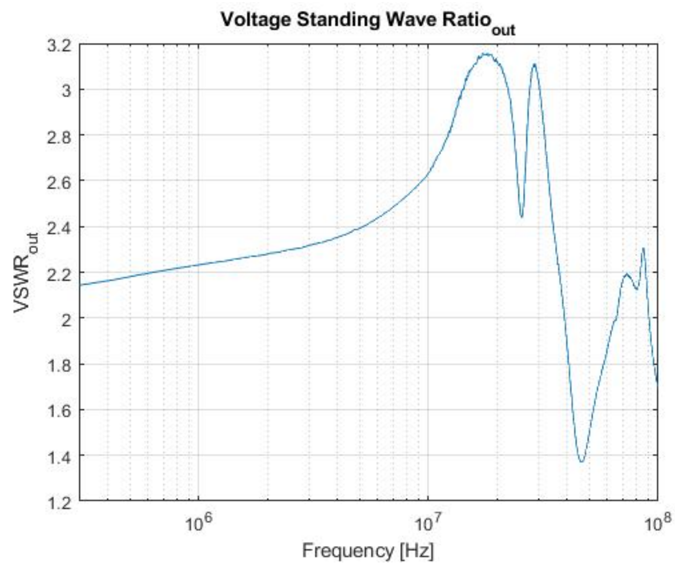


Figure 3.5

Then to compute the *Insertion losses*, we noted a difference in the formula with the theory presented in class and the results were not meaningful. For this reasons, we used instead:

$$IL = 20log_{10}\Big(\mid S_{21,ds} \mid\Big) \tag{3.7}$$

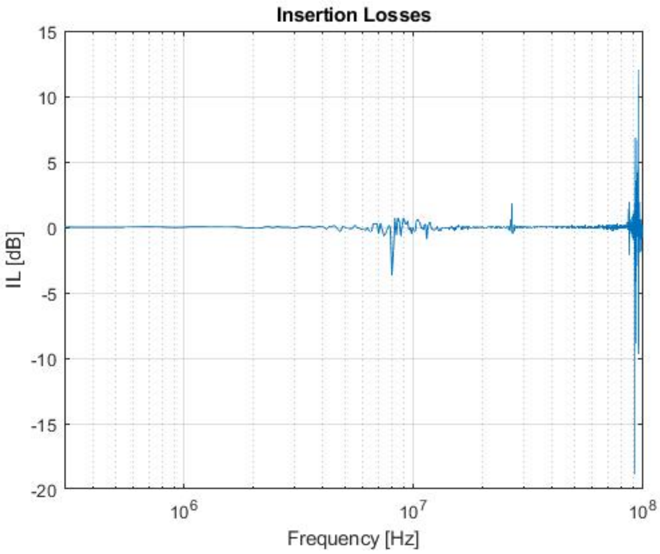


Figure 3.6

The *Common Mode Rejection Ratio* is computed as:

$$CMRR = 20log_{10}\left|\frac{S_{21,ds}}{S_{21,cs}}\right| \tag{3.8}$$

The Fig: 3.7 shows that is maintains its simulated behavior.

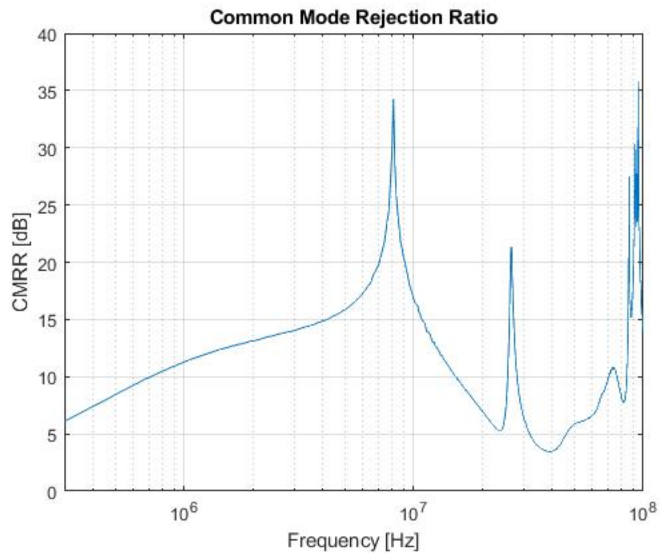


Figure 3.7

Then *Magnitude* and *Phase imbalance* are evaluated as:

$$MIMB = 20log_{10}\left|\frac{S_{21}}{S_{31}}\right| \tag{3.9}$$

$$PHIMB = \angle\left|\frac{S_{21}}{-S_{31}}\right| \tag{3.10}$$

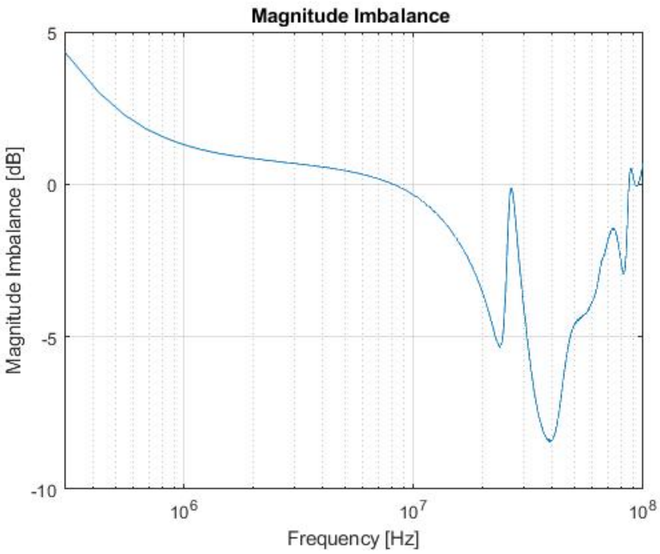


Figure 3.8

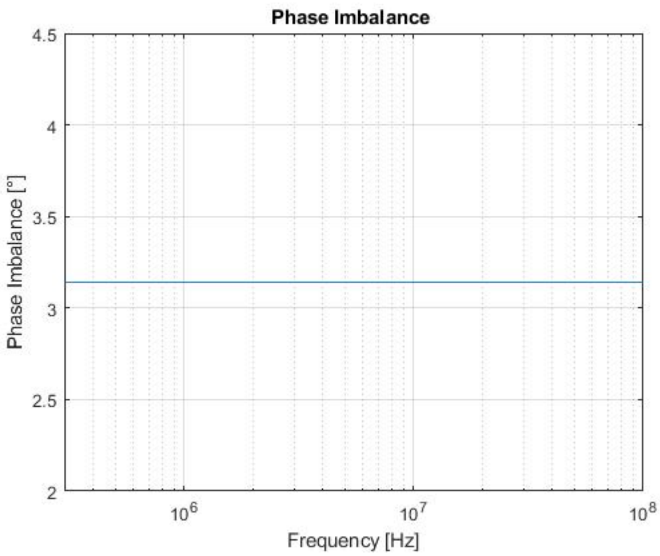


Figure 3.9

| | Specifications | Bandwidth | Measured | Measured Bandwidth |
|---|---|---|---|---|
| $VSWR_{in}$ | $< 2$ | $0.08 - 100MHz$ | $< 1.35$ | $0.3 - 100MHz$ |
| $VSWR_{out}$ | $< 2$ | $0.08 - 100MHz$ | $< 3$ | $0.3 - 10.5MHz$ |
| $IL[dB]$ | $< 1dB$ | $0.14 - 23MHz$ | $< 1dB$ | $0.3 - 7MHz$ |
| $CMRR[dB]$ | $> 20dB$ | $1 - 20MHz$ | $< 1dB$ | $7 - 9MHz$ |
| $Magn.Imbalance[dB]$ | $< 1dB$ | $0.77 - 20MHz$ | $< 1dB$ | $2 - 9MHz$ |
| $PhaseImbalance[dB]$ | $< 10°dB$ | $1 - 22MHz$ | $< 3.5dB$ | $0.3 - 100MHz$ |

Table 3.1: Summary of the performances of the implemented balun, respect to the measured values.